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Insect Pathology: The Field Concerned, Training Required, and Opportunities Possible[1]

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During the past several years, the field of insect pathology has "come of age," so to speak, and has been enjoying somewhat of a revival with regard to the interest taken in it by entomologists and others. This renewed interest, engendered by several factors, is reflected in the recent establishment of research laboratories and academic courses in various parts of the world. Since there is an increasing demand for information regarding the nature of the field concerned, the type of organization required to maintain it, the training necessary to prepare for it, and the opportunities available to those who wish to enter it, there is reason to believe that a brief general discussion of these aspects would be of pertinence and value at this time. Although there is a real temptation to wax philosophical concerning our subject, for the present it is perhaps safest to avoid such an approach and to limit our remarks to a rather prosaic presentation of factual material.

What Constitutes Insect Pathology?

First of all it is important that there be a general understanding of what is meant by the term "insect pathology." Although the word "pathology" was used in connection with diseases of insects at least as early as 1865, it is only recently that the term "insect pathology" has been used in a formal way to designate a rather definite field of endeavor.

"Insect pathology" may be loosely defined as constituting that branch of biology embracing the general principles of pathology as they may be applied to insects. In a broad sense, the term refers to the study of the cause, symptomatology, and epizootiology of the diseases of insects, and to observations relating to the structural, chemical, and functional alterations in the body of the insect resulting from disease or injury. From a practical standpoint, it may also include the consideration of certain aspects of the general field of insect microbiology and certain of the biological relationships existing between insects and microorganisms not pathogenic to them. Another logical viewpoint would be to consider insect pathology as a part of the general field of invertebrate pathology. In any case a definition such as that just given would be applicable.

The manner in which insect pathology concerns itself with the diseases and injuries of insects is analogous to the way in which plant pathology concerns itself with the diseases and injuries of plants. As it is with the plant pathologist, so it is that the insect pathologist requires a knowledge of at least certain aspects of bacteriology, virology, mycology, protozoology, immunology and general pathology in addition to a familiarity with all the basic sciences. It may be mentioned here that for many years much of the work of insect pathology was conducted by plant pathologists. This situation prevailed largely because of the preeminence of fungi (well-known to plant pathologists) among the then-known insect pathogens, and because of the frequency with which certain insect diseases were observed by plant pathologists in the course of their usual work.

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[1]Contribution from the Laboratory of Insect Pathology, Division of Biological Control, College of Agriculture, University of California, Berkeley.

Then too, the entomologist concerned about diseases in the insects with which he happened to be working frequently had no one to turn to for help in making a diagnosis except the plant pathologist. The situation has now changed, however, and insect pathology has come to be recognized as an autonomous field in its own right; a field much broader than originally conceived and one in which all types of etiological agents are recognized as responsible for disease in insects.

Actually, the term "insect pathology" includes, in addition to diseases caused by microorganisms, a consideration of those maladies arising from injuries, faulty metabolism, chemical poisoning, and any other factor which causes dysfunctions and abnormal changes in the insect's body. Usually, however, these conditions are considered by the insect toxicologists and physiologists, but strictly speaking it should be remembered that when an insect is sickened or killed by a physical injury or by a toxic chemical agent, a pathological state results and a study of this pathology is amenable to the same techniques and analyses as is a pathological state resulting from the activity of living microorganisms.

While insect pathology is a separate and distinct branch of entomology, it is intimately related to nearly all other types of entomological pursuit with which at times there may be considerable dovetailing and overlapping. In another publication the writer has discussed in some detail the interrelation between insect pathology and the other branches of entomology, and has pointed out the nature of the contributions that insect pathology has made and is making to the rest of entomology. While the contributions it is making to insect physiology, biological control, and economic entomology generally are rather obvious, it is a fact that direct contributions to such branches as insect taxonomy, insect toxicology, and medical entomology can be enumerated.

During the past ten or fifteen years it has become increasingly apparent that the field of insect pathology needed not only formalization but also a more definite and direct approach to the solution of its problems. The study of insect diseases as incidental to or as a stepchild of the investigation of other problems was proving itself inadequate. Isolated observations, of excellent quality, were all too frequently left hanging by themselves without their being integrated into the mass of knowledge and information concerning insect diseases that could have been gathered together. Separate, distinct, and well-organized projects dealing solely with the diseases of insects were needed, and among the first to take well-planned steps in this direction was the U.S. Department of Agriculture. This agency delegated special experts to the study of the diseases affecting the honeybee, and later, set up a special unit for the investigation of the milky diseases of the Japanese beetle, a serious pest in eastern United States. Most of the latter work has been accomplished at the Japanese Beetle Laboratory, Moorestown, New Jersey, through which there has been a great amount of cooperation with various state agencies.

For some time prior to World War II, Professor Harry S. Smith, Chairman of the Division of Biological Control in the College of Agriculture at the University of California, envisioned the addition to his Division (then the Division of Beneficial Insect Investigations) of two new types of biological control work. The first of these was a unit concerned with the control of weeds through the use of insects. The work was initiated in 1944 in cooperation with the U.S. Department of Agriculture. The second was a unit concerned with the diseases of insects and their use in the control of destructive insects. This hope was realized with the establishment of the Laboratory of Insect Pathology in 1945.

The research work of this laboratory was arranged according to projects which covered almost all aspects of the subject. Thus, at the present time the functioning projects may be listed under the following broad headings:

(1) Bacterial diseases of insects
(2) Fungous diseases of insects
(3) Protozoan diseases of insects
(4) Virus diseases of insects
(5) The nature and properties of insect viruses
(6) Examination of disease material submitted for diagnosis
(7) Miscellaneous research and experimentation
   (a) Insect microbiology
   (b) Entomogenous nematodes
   (c) Numerous other temporary projects

Projects 1 to 4 above are conducted from two general standpoints: fundamental research and practical application. In most cases the fundamental aspects of investigation are so closely related to the applied phases that it is difficult to draw a definite line between them. Usually, a certain amount of fundamental research necessarily precedes any attempt to use the microorganism concerned in a practical way.

By 1946 the Division of Entomology of the Canadian Department of Agriculture had initiated an extensive program for the purpose of studying the microbial diseases of forest insects. The virus diseases came in for special attention. Fundamental studies along this line are being pursued at the Forest Insect Laboratory at Sault Ste. Marie, Ontario, where a large modern laboratory especially for work on insect diseases is being completed. It seems apparent that we can look forward to seeing the realization of highly productive research in insect pathology by the fine staff being assembled at this laboratory. In addition, the Biological Control unit of the Division of Entomology is contemplating the application of insect pathology and microbial control to insect pests of Canada other than those of the forests. There have also been established cooperative projects between these Canadian groups and the Commonwealth Bureau of Biological Control.

Although the writer is not aware of other large organizations doing research in insect pathology, individual workers and small groups in several countries (e.g., England, France, Germany, Russia, Argentina, Egypt, and India) are productive in this field. It is hoped that through a broadening of outlook and a condensation of effort larger centers of activity may result from the labors of these small groups.

Training Required for Insect Pathologists

It is recognized that to a certain extent one can be self-trained in almost any specialty, and in the past those who have concerned themselves with the study of the diseases of insects have usually had no formal training in the field nor have they even depended upon an empirical knowledge of the subject. To succeed under such circumstances is all the more credit to the individual, but with the growth and development of any science it sooner or later becomes necessary to have highly-skilled specifically trained investigators. Insect pathology has reached this point in its development, especially if the individual is to be considered as trained in all aspects of the subject.

At the present time, the only educational institution offering a complete and formal course in insect pathology is the University of California at Berkeley. Although the research program in insect pathology at this university was initiated in 1945, the academic program was not begun until the spring of 1946. The course is given each spring semester (16 weeks) and consists of 3 one-hour

lectures and 1 three-hour laboratory session per week. The only prerequisites are that the student should have had beginning entomology and at least one course in the microbiological sciences (mycology, bacteriology, or protozoology). The course, as it is listed in the curriculum of Entomology and Parasitology, is described in the catalogue as: "General insect pathology and microbiology including the biological relationships between all types of microorganisms and insects. Detailed study of bacterial, fungous, virus, and protozoan diseases of insects; noninfectious diseases of insects; histopathology. Use of microbial agents in the control of insect pests."

The subject matter of this course may be further described under the following general headings:

(1) Introduction (scope; historical aspects; etc.)
(2) Noninfectious diseases
  (a) Mechanical, physical, chemical injuries
  (b) Diseases of nutrition and metabolism
(3) The extracellular microbiota of healthy insects
(4) Intracellular microbiota
(5) Principles of infection and epizootiology
(6) Resistance and immunity
(7) Classification and description of symptoms and pathologies
(8) Bacterial infections
(9) Fungous infections
(10) Virus infections
(11) Protozoan infections
(12) Nematode infections
(13) Applied insect pathology and biological control

The laboratory period is arranged to correspond more or less with the subject matter being covered in the lectures. Certain aspects of disease processes in insects are best presented to the student in demonstration form and such demonstrations are a part of the laboratory work. The textbook used in the course is "Principles of Insect Pathology" published for the writer by McGraw-Hill Book Company.

In addition to the lecture and laboratory course in insect pathology, the University of California also offers graduate instruction and seminar sessions in the subject. The graduate work prepares the student for the degrees of Master of Science and Doctor of Philosophy. The student must have satisfied the requirements of the University necessary for good standing in the Graduate Division. His background must include sufficient credits in entomology from an accredited institution which would enable him to continue his graduate work in entomology at the University of California. In many cases it is advantageous for the student to take his higher degrees in the general field of biological control with special emphasis on insect pathology.

In addition to the general educational requirements, graduate students seeking a Ph.D. degree in insect pathology are required to complete the following courses or their equivalents: General entomology, insect morphology and histology, insect physiology, systematic entomology, insect ecology, biological control, insect pathology, bacteriology, mycology, protozoology, and seminars. In addition the student must have a reading knowledge of at least two foreign languages, and must, of course, conduct a satisfactory program of research and present a thesis. When at all possible, the student is also asked to take, or at least to audit, courses in microscopical technique, cytology, plant pathology, biometry, advanced bacteriology, and general parasitology.

Although the academic training in insect pathology presented at the University of California is the most detailed and complete being given anywhere, it is not the only institution giving instruction in this subject. A certain amount of guidance along these lines is being given interested students at Queens University (under Professors G. B. Reed and A. S. West) and at Ontario Agricultural College (under Professor L. A. McDermott). In the United States some universities have arranged to send their students to the University of California for a period of specialized academic and research training in insect pathology after which the student returns to his original institution to complete the requirements for his degree in entomology.

Opportunities in Insect Pathology

It would be an extremely precarious undertaking to attempt to predict the future of a field at the particular stage in which insect pathology finds itself. If the value of the field were limited solely to its application in the biological control of insect pests, then one's prediction would have to be similarly limited. Fortunately this is not the case; insect pathology has much to offer in addition to its very important application in the field of biological control. As far as the practical side is concerned, however, the writer has stated his opinion elsewhere (J. Econ. Entomol., 1945, *38*, 591-596) to the effect that while microorganisms should not be envisioned as the panacea to insect control, yet there is no reason for the mood of pessimism held in some quarters. Enough has been done to indicate that the use of microorganisms in the control of noxious insects holds considerable promise in spite of several well-known abortive attempts in the past. Indeed, one of the primary reasons for certain of the past failures has been the fact that the work was not done by men trained or experienced in the fundamentals of insect pathology. Accordingly, there is room in entomology for more workers trained basically as entomologists but having the additional and special training of insect pathologists. It is perhaps not too venturesome to suggest that entomologists trained in insect pathology should be included on every staff of biologists engaged in an extensive ecological study of insects. The same is true for extensive field studies in economic entomology. Too much of the ecological and other data collected is not interpreted with regard to the natural occurrences of disease in insect populations. Unless an entomologist is properly trained he will usually have considerable difficulty in diagnosing and interpreting disease material found in the field. This, then, is perhaps the largest area of opportunity for men trained in insect pathology.

In addition to the opportunities for insect pathologists in the fields of biological control, insect ecology, and economic entomology generally, there are real, although limited, opportunities in fundamental research and teaching. There is a growing realization on the part of many university departments of entomology that the subject of insect pathology belongs somewhere in their curriculum. One very obvious reason why more colleges and universities are not teaching the subject is the relatively few individuals available to present it. However, it is probably for the good of the science that there is a slight scarcity of trained men rather than an overabundance of them.

In general, the field of insect pathology appears to have a very promising future especially with regard to the fruits that are to be realized from its research. Not only will our increased knowledge of the subject provide a better understanding of insect life, but biology in general will be enriched. Those whose interests compel them to be insect pathologists, regardless of whether or not there are to be great practical applications of the field, are probably destined to be among the happiest and most satisfied of biological scientists.

Wohlfahrtia (*Diptera, Metopiidae*) Myiasis of Mink in Alberta

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In nearly every year our attention is drawn to one or more cases of human myiasis in various places in Alberta. Unfortunately, in every instance where these have concerned infants, the larvae had already been removed and placed in alcohol. We have submitted a number of these larvae to Dr. E. M. Walker, at Toronto University for determination. He has not cared to commit himself by identifying first instar larvae but he classified all specimens which were in the 2nd or 3rd instar as species of *Wohlfahrtia*. He, further, suggested that they might be *meigenii* Coq. At the time when he identified them for us, it was believed that this species, though described from Europe, did occur in Western Canada.

Fly maggots which have been removed from 'teen-aged children and adults proved to be *Sarcophaga spp.*, Calliphorids or *Hypoderma*.

The clinical history of all cases of infant myiasis, however, has been so similar and all follow so closely the pattern described by Walker[1] and Ford[2] for *W. vigil* (Walk.) in Eastern Canada, that we believe all of them to have been caused by a species of *Wohlfahrtia*. This type of myiasis has been reported from Ft. Assiniboine in the north almost to the International boundary to the south.

In 1937, a student at this University brought us a white rat which was suffering from myiasis of the foot. The single larva implicated was bred to maturity and the case was described by Morrison[3]. From the literature[4] which was available to us, we had no hesitation in deciding that the adult represented the species which was there recorded as *W. meigenii* (Sch.). We drew attention to the fact, however, that this was undoubtedly a case of primary myiasis, whereas *meigenii* is stated to be a simple carrion feeder in Europe. The suggestion was, further, made that the western fly might be a light-coloured variant of the eastern *vigil* (Walk.).

In the following year, Dr. D. G. Hall, of the U.S. Bureau of Entomology. kindly examined all of our Metopiid material. He informed us that our reared and captured specimens of the so-called "*meigenii*" were, in reality, *W. opaca* (Coq.). He, however, classified a single dark coloured male, captured at Athabasca Landing, as *W. vigil* (Walk.).

Early in July, 1948, we were informed that, during the preceding few weeks, mink kittens in a number of yards in the vicinity of Edmonton had been heavily infested with fly maggots. By the end of the summer, 130 breeders had reported varying intensities of infestation. By July 3rd, on which date we received our first information, the last of many hundreds of maggots had been removed and all had been destroyed. Fortunately, for us, however, Dr. Wilton, Provincial Veterinarian, had obtained a few living larvae from mink kittens prior to this date and he kindly turned them over to us for rearing. At the same time, he brought us two infested Felis kittens. He reported a similar infestation of a young rabbit and, on the following day, we received a living larva which had been removed from a blue fox pup.

In consequence of the diversity of infestation among young animals, we anticipated that we would hear of cases of infant myiasis but the only evidence we could obtain was the statement that a surgeon had told a friend that he had been called upon to remove "more maggots from infants than is usual, during June". In January, 1949, we received a single larva, in alcohol, which had been

removed from an infant at Coleman, Alta., in 1948, but were unable to obtain further data regarding it.

We reared several adults from both types of kittens by placing them on beef. The females were typical *opaca* in colour, while a lone male conformed with *vigil.* Since neither sex of the latter species is reported to have the abdomen densely pollinose, and the females appear to be identical with those determined for us by Hall as *W. opaca* (Coq.), we are provisionally referring all of our material to this species.

Occasional collections of adult flies in yards and from nearby flowers were made during July and August but these yielded no relatives of *Wohlfahrtia* closer than various species of *Sarcophaga.*

The owner of the worst infested yard which we visited informed us that, on one occasion, upon opening a nesting box, he discovered a fly in the act of larviposition. It had already deposited about twenty larvae on the head of a kitten.

The history of infestation in this yard may be taken as fairly typical of others, even though they were less severely affected.

In 1927, at which time the owner was rearing fishers, two of these kittens were infested. Between that date and 1948, he saw no evidence of myiasis in any animals. In this year, however, he observed the first sign of trouble on June 7th. From that date, onwards, daily infestations increased till they reached their height, with about twenty new cases daily, between June 17th and June 20th. After the latter date, the trouble subsided and the last maggots were removed on July 2nd. Out of a total of 429 kittens in this yard, 135 had been infested.

At this season, infestation was confined to the kittens, even though the mother invariably inhabited the nesting box with them. Later in the summer we learned that three adult mink became infested, one in mid-July, and two on about August 7th, in near-by yards.

Attention to the presence of larvae was frequently drawn by the mother sedulously licking the affected area. The majority of kittens which we examined were infested in the groin or on the hind legs, but this was not universal. It would appear that the presence of moisture, either on the fur or on the body surface, may be a factor of some significance in determining where the wandering first instar larvae will finally come to rest and begin to digest away the skin.

All kittens in heavily infested yards were examined at least once daily. Any larvae found were squeezed by hand from the superficial cavities which they inhabited, the latter were treated with an ointment and were then drenched with Dettol or hydrogen peroxide by the insertion of a syringe. Either treatment effectively terminated the trouble. The only losses occurred when, in five cases, the maggots entered the rectum, from which it was not possible to remove them. The kittens became seriously bloated and all of them died.

During the early part of the summer, some breeders were of the opinion that kittens which had been infested by a dozen or more larvae were somewhat stunted in their growth. There was, however, no observable difference at pelting time in November, when it was very difficult to detect many scars, either on the outside or on the inside of the pelts.

Infestation centred around Edmonton and its vicinity though a number of cases occurred in yards over sixty miles to the west and forty miles to the south. Early reports of similar trouble in the neighbourhood of Lesser Slave Lake, about 120 miles to the north, proved to be unfounded.

There is indefinite evidence that there may have been a few cases of mink myiasis in 1947. If this be correct, all were unreported. The suggestion has been

made that the breeders feared they would be accused of maintaining unsanitary yards. In our experience, the trouble in 1948 was most in evidence among the best managed yards, all of which were kept scrupulously clean. We were unable to obtain any evidence that the proximity or otherwise of large masses of flowering plants, such as sweet clover which is favoured as food by the adults, affected the severity of the attack.

We have no suggestion to offer in order to account for this unprecedented "outbreak" of a widespread, but normally, scarce insect, and have no reason to be apprehensive that, from now on, mink breeders must be prepared, annually, to face this menace on a similar scale. Normally, it would seem, this fly must maintain its small population at the expense of some of our native rodents or similar animals. Of these, the snowshoe rabbit is most prevalent throughout the infested territory, while chipmunks have a scattering population. "Gophers" have increased in numbers during recent years to the south of Edmonton but are almost unknown in much of the affected territory. It is safe to assume that few, if any, larvae which have infested commercially raised mink or other kittens have had an opportunity to mature. These animals serve more as "traps" for the reduction of the fly population than otherwise.

An examination of numerous yards indicated a definite relationship between an absence of shade and the intensity of infestation, despite the fact that actual larviposition would appear to occur chiefly in the darkened nesting boxes rather than when the kittens are running in the open pen.

Several yards have been established in what was originally "bush" country. In most of these, the small aspen poplars have been left standing in the aisles throughout the yard. We could learn of a single infested adult (in mid-July) in a dozen or more shaded yards. On visiting one of them, however, we learned that two kittens in one pen had been severely infested. We asked if we might see it. On the south side of the small wooded area, which contained the rest of the yard, stood four pens, entirely free from shade. The infestation had been confined to one of these.

At Wabamun, 40 miles to the west of Edmonton, all yards are located among spruce trees. There were no cases of *Wohlfahrtia* infestations in this area but, twenty miles still further west, a number of yards, all of which are in the open, were generally infested.

We would hesitate, at present, to advocate tree-planting in all yards as a precaution against future infestations since we do not anticipate a frequent repetition of the trouble. One year's observations, however, do suggest that this might constitute a method for permanently reducing the incidence of mink myiasis. Such a method should prove to be more simple than would the installation of the ingenious fly-proof doors to the nesting box exits, as designed by Kingscote[5], or the annual spraying of nearby vegetation with DDT for the possible destruction of adults before larviposition.

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Hornia minutipennis Riley: A new Record and some notes on Behaviour. (*Coleoptera, Meloidae*)

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Occurrence, Distribution, and Taxonomy

One female and a damaged male of this rather extraordinary physogastric beetle were brought into the laboratory early in November, 1946. A few days later four further males and three females were collected from the same situation, a roadside bank of hard calcareous clay facing SSW, at Mill Creek, Edmonton. In view of the many references to this insect in entomological literature, but the scanty information given on it, some laboratory observations were considered worth while.

All specimens were taken from cells of an anthophorid bee later identified as *Anthophora sodalis* Cresson, and it would appear that the colony was of long standing, although now almost exterminated by a variety of parasites. In addition to the beetle *Hornia,* many cells were inhabited by bombylid and other flies, chrysidid wasps and megachilid bees.

This insect was first described by Riley[6] who recorded it as parasitising *Anthophora sponsa* Smith (=*abrupta* Say), and erected the genus *Hornia* for it. Riley states in his description of the genus, that the tarsal claws are simple, but in all the specimens examined here they are armed with a long straight basal tooth, which is however transparent and colourless, and particularly when the specimen is mounted in balsam, rather difficult to see. This tooth is virtually identical with the structure figured by Williams and Hungerford[9] for *Hornia neomexicana* Cockerell (=*Hornia gigantea* Wellman), who suggest that this was overlooked by Wellman[8].

Mickel[4] has shown that the characters on which the genera *Hornia* Riley and *Leonidia* Cockerell have been separated do not have generic value, and this author unites the two genera. Linsley[2], reviewing the systematics of the genera *Hornia* and *Allendesalazaria* Escaleria, divides *H. minutipennis* into two subspecies, *H. m. minutipennis* Riley and *H. m. occidentalis* Linsley, the latter only, having the basal tooth to the tarsal claw. Mr. J. W. MacSwain of the University of California has kindly examined the material used in these observations, and regards it as representing a new subspecies, intermediate between *H. m. minutipennis* and *H. m. occidentalis* (*in litt.* 28 September, 1948). It is well known that *Anthophora* colonies continue in more or less complete biological isolation, for very long periods, probably several centuries, so that further studies of these interesting parasitic species, especially the regular observation of colonies of known history should prove most interesting, particularly from the evolutionary aspect.

Beetles of this genus have previously been recorded from Missouri, New Mexico, Kansas, Colorado, Washington, D.C., Montana, California, Oklahoma, New York, Texas, Mexico, and Lethbridge[7], so that Edmonton constitutes a northern record for the group.

Adult Structure and Behaviour

The beetles as taken were apparently adult, in that they were winged and proceeded to mate and lay eggs without further moults. They were surrounded, however, by two exuvial layers, from which all specimens emerged within three days, leaving both cast skins at the same time by moving out backwards through the posterior ends. The tracheal linings of the exuviae, however, without excep-

tion run anteriorly from the exuvial spiracles; no explanation of these somewhat incompatible facts can at present be offered. Peristaltic waves continued to pass backwards along the abdomen for some time after emergence. These waves might possibly be connected with locomotion, which is also assisted by a forward levering movement from the tip of the abdomen, and would, indeed probably be impossible without such abdominal assistance, at least in the female.

Mating was preceded by energetic courtship behaviour on the part of the male, which included kneading and sometimes actual laceration of the female abdomen with the mandibles, although there was apparently no feeding on the body fluids thus made available. Actual mating was first observed to occur twelve hours after the emergence of the female, and eighteen hours after emergence of the male, the process, which was repeated several times by any one pair, occupying from 4 to 12 minutes.

The first eggs were laid six days after mating. The eggs are smooth translucent, yellow, and somewhat elongate, and were laid at random in batches of 30-40, at the rate of one egg about every 45 seconds. The end of the abdomen of the female is tucked forward and to one side, and is then drawn back, leaving the egg which is very slightly sticky, in front of the end of the abdomen. The greatest number of eggs laid by any one female was 240, over a period of 14 days, but dissection of this female revealed several hundred eggs in various stages of development in each ovary, and probably close to a thousand eggs could be laid.

Many widely different food materials were offered to the adults, but neither males nor females could be seen to take in any food whatsoever between the time of their emergence and their death. Although the males are almost equally physogastric with the females on their emergence, the abdomen of the male shrinks rapidly, and within a week of emergence is very mis-shapen and much smaller than that of the female. This is interconnected with the greater mobility shown by the male, although even a male in this condition moves but slowly, and given unfavourable conditions such as a smooth, slippery, or uphill surface is quite incapable of locomotion.

Both males and females are photonegative in their reactions; the males especially, owing to their greater mobility, taking up positions underneath or on the darker side of whatever cover was available. Males and females kept together on moist sandy soil, however, exhibited no nest making activity, and eggs were laid at random on the surface of the soil.

Development and Life History

Eggs were incubated at room temperature (68°-70°F.) in small tubes over moist sand, giving a relative humidity of about 60 per cent. During the first few days after the egg is laid faint reticulate sculpturing, presumably the imprint of the follicular cells, appears on the chorion. By the tenth day the body somites were discernible through the chorion, and on the 14th day eight abdominal somites could be clearly seen, together with the head and thoracic appendages, apparently in normal orientation with respect to membranes. The first eggs hatched late on the 20th day.

Just before hatching, the three pairs of legs, each leg with three tarsal 'claws', the eyes and the mandibles, are clearly visible. Hatching takes place by the rupture of the chorion in the mid dorsal region of the thorax, which is brought about by the larva doubling itself into an S-shape, swallowing the amniotic fluid, and thus expanding the thorax and forcing the paired hatching spines on the meso and metathoracic terga against the chorion. The swallowing of the fluid is

accompanied by slight movements of the mandibles. The thorax emerges first from the resulting split, followed by the head, and then the abdomen, the whole process occupying about an hour.

On emerging from the egg the triungulins are translucent, and creamy white in colour, the only pigmentation appearing in the hatching spines and the tips of the mandibles. Pigmentation proceeds rapidly and is complete within 24 hours.

In general structure, the first stage larvae agree very well with the comparative description of them given with that of *Tricrania sanguinipennis* Say by Parker and Böving[5]. They are, however, very much larger, relative to the diameter of the hairs of *A. sodalis* than is the triungulin of *T. sanguinipennis* relative to the bee hair with which it is figured by these authors. The hairs of *A. sodalis* would undoubtedly fit *into* the grooves in the mandibles of the *Hornia* triungulin. It would appear that this may operate as an important factor in host selection since the hairs of many other genera of bees examined were found to be small enough to slip through these grooves, while those of still other genera were too large to get into them at all.

The failure of triungulins to feed in the laboratory prevented the rearing of further instars. The two exuviae within which the adults were discovered are assumed to be those of the fourth and fifth instars, and are shown in figures 4 and 5. Search in the field at various seasons failed to reveal any specimens of second or third instar larvae, or of the sixth instar or the pupa. A thorough search of a number of cells, including a search of the alimentary canal of the inhabitant, disclosed no trace of the exuviae of the sixth instar or the pupa. In view of the increasing inactivity of the later stages, these are presumably extremely attentuated, but even so it is hard to see how they could be overlooked in such a small container as an *Anthophora* cell. Linsley and MacSwain[3] report that the sixth larval exuvium of *H. m. occidentalis* is worked backwards to the posterior end of the body and remains attached to the ventral surface of the pupa.

Behaviour of First Instar Larvae

In behaviour, however, these triungulins were very different to those of *Tricrania*. It was found quite impossible to get them to take any food or water at all; pollen, honey, sugars, egg yolk and egg albumen, and portions of *Anthophora* larvae, were all consistently ignored and refused. This made it impossible to rear further stages in the laboratory.

Triungulins of other Meloid species have been reported as climbing on to flowers to await their bee hosts; these larvae, however, showed no tendency to do this, and larvae placed on flowers, or other parts of flowering plants tended to leave them rather than to stay or to climb on to the flowers. Of three batches of 20 released at random on the flowers, plants and soil surface of potted chrysanthemums, only one insect was, after 24 hours, recovered from a flower, and the insect in question was dead. The majority were recovered from the glass dish outside the flower pot. Stellate hairs from local plants (probably *Shepherdia* or *Elaeagnus* spp.) were found associated with the larvae in the *Anthophora* cells.

Triungulins are frequently described as an active stage; these specimens were not normally active, although responding vigorously and immediately to various stimuli. In the absence of such stimuli the larvae remained continuously quiescent. The nature of this response, and of the stimuli which evoked it were most interesting. The former may be conveniently termed the grappling response, and in its fullest form the general activity is increased, the insect raises the first pair of legs and waves them in the air, at the same time arching the thoracic and cervical regions upwards, and opening and closing the mandibles alternately

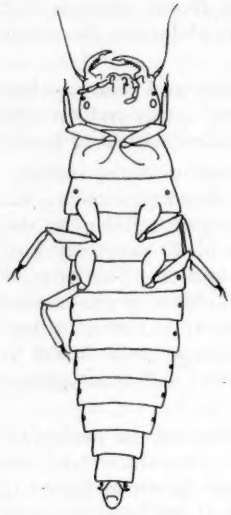

Fig. 1
First instar or triungulin larva. x60.

Fig. 2
Tarsus of triungulin. x300.

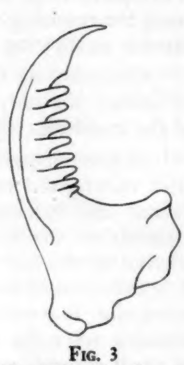

Fig. 3
Mandible of triungulin. x300.

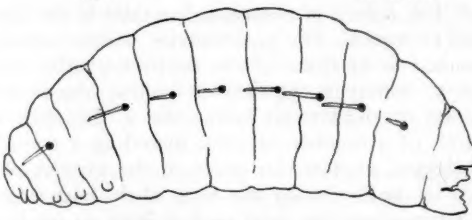

Fig. 4
Exuvium of 4th instar, x7.

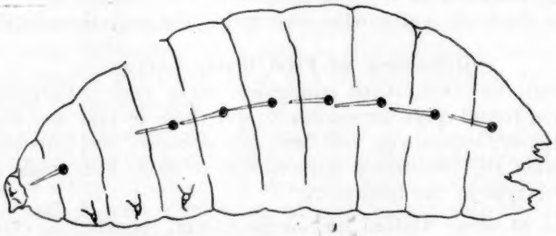

Fig. 5
Exuvium of 5th instar, x7.

throughout the duration of the response. Such a response if occasioned at appropriate moments is clearly of value to the insect in improving its prospects of accomplishing the next stage of its development, and it is most interesting to note that the stimuli which evoke this response are precisely those which the insect may be expected to receive when a suitable bee comes into its vicinity.

These stimuli, as determined in the laboratory, are as follows: the approach of a small dark object from above; air currents, especially from above; a musical note of pitch E below middle C (frequency 160). Any of these stimuli applied alone resulted in a partial response only, usually involving all the activities except the raising of the front legs; the application of two or more stimuli simultaneously resulted in the full reaction as described above.

Estimates of the frequency of wing beat of the bee *A. sodalis* were made, using adults which were reared in the laboratory from larvae taken at the same

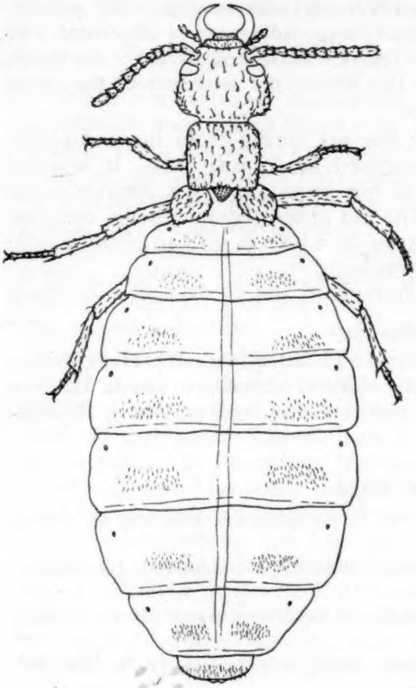

FIG. 6
Adult female of *Hornia minutipennis*, x7.

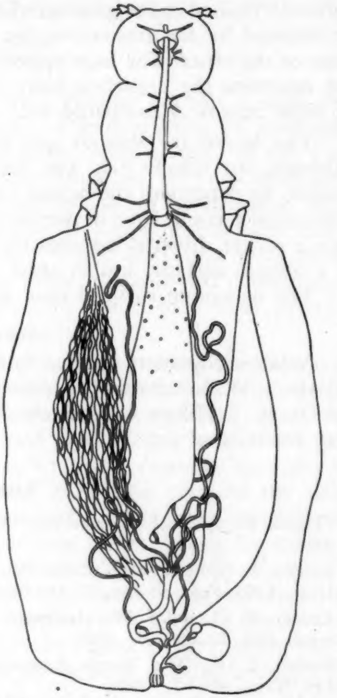

FIG. 7
Adult female dissected from the dorsal aspect to show alimentary and reproductive systems, x7.

time as the *Hornia* specimens. The note emitted by the vibrating wings while the insect was 'fanning' was middle C (frequency 256); when in flight the pitch rose to E above middle C (frequency 320). If, as Hannes[1] states, the note emitted represents a frequency twice that of the wing beat, the frequency of wing beat is the same as that of the note found to evoke the grappling reaction in *Hornia*. This clearly is potentially another very significant factor in host selection.

In walking over the shorter hairs of the bee, the triungulins place the central 'claw' in front of the hair, while the two basal setae are placed one on either side, the end of the hair being held at the junction of the three parts of the foot. In this way a satisfactory purchase on the end of the hair appears to be obtained. The main hold, which presumably prevents the larva from being dislodged while the bee is in flight, is almost certainly obtained with the mandibles. If larvae which have obtained a hold with the mandibles are removed with a pair of forceps, the hair or hairs invariably come away with the larva. Measurements of basal diameter of hairs of *A. sodalis* from the ventral side of the head and the prothorax, where these larvae are reported to attach, gave a range of figures from 0.005 to 0.006 mms. The mean distance between crests of the *Hornia* triungulin mandibular serrations was 0.008 mm. The bee hairs, of which several may be grasped, may thus clearly be wedged into the tapering grooves, near the open end. Parker and Böving suggest that in *Tricrania* the hairs are retained in a hollow formed between the nasale and the two mandibles; in *Hornia*, however, they can

definitely be held in the grooves of the mandibles and additional grip may possibly be obtained by the grooves of one mandible being pulled out of alignment with those of the other. The hairs appear to be retained in these grooves by the nasale, and doubtless the branched hairs of the bee favour the retention of the larvae on these insects as compared with others.

The larvae are able to spin a very fine silk thread from the end of the abdomen, by which they can hang suspended head downwards. It was not possible to determine the actual source of this thread, and it is difficult to see what value it could have in normal life. The end of the abdomen is also equipped with a sucker directed towards the ventral side, which is used to obtain a hold on a smooth surface, and to assist in locomotion.

The maximum survival time of the triungulins was 27 days after hatching.

Acknowledgments

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A Critique on Insect Chemical Control Methods**

By A. D. Pickett*

While it is said, with some truth, that man's greatest conflict is with man, and although that conflict shows little indication of soon abating, he faces other conflicts which are also very real and immediate. Man is one of the many competing species in the world's interdependent fauna and his very existence is inextricably interwoven with that of the other animals in his environment. Man's progress may be measured largely by the degree to which he has been able to shape his environment to meet his needs and few would deny that in so altering his environment he has made human existence more tolerable and consequently, more satisfying. At least few of us would elect to return to a more primitive stage of human history.

The world's faunal population is competing for food and this has been going on since animal life began; it will continue as long as animal life continues. In order to provide food supplies in greater abundance and with less hazard man developed agriculture. The methods he has used, taking an over-all view, have been destructive to the natural resources upon which he depends. Consider the fertile lands that have been changed to deserts in various parts of the world including the western hemisphere where agricultural pursuits have been followed for only a few decades. Yes, man has made progress in developing his ability to increase the quantity of agricultural products produced per unit of effort but in doing so colossal blunders have been made in the exploitation of natural resources. If we are to heed present trends in population increase, how long can we continue with the highly destructive and wasteful practices found in agriculture today? With all of our improved methods where are our present policies leading us?

Among the very real competitors for the food on our dinner tables are insects and related arthropods. This has probably always been so. Insects are a very important group of animals and they compete with man more effectively than any other group for the world's food supply. It is not necessary to explain here about their huge numbers, their methods of rapid reproduction, voracious appetites, or their adaptability. It is sufficient to say that as competitors they are extraordinarily efficient. For thousands of years man accepted insects as part of the normal environment over which he had little or no control, and it is only within the last half century that we have actually made any real attempt to reduce their effectiveness as competitors.

While some materials, such as certain plant extracts, have long been used as insecticides to a limited extent, there appears to be few records of the successful application of chemicals to protect plants until Paris Green was used in 1867. From that time on, the use of chemicals for the control of plant pests has been gradually accelerated until today the manufacture of insecticides and other pesticides is one of our big business enterprises. The insect most responsible for initiating the use of insecticides was the Colorado potato beetle. Some day the insecticide industry will probably raise a monument to this 'bug' which went berserk and instead of continuing to feed on its normal host, the buffalo burr, attacked the most important food plant—the potato—planted by the new settlers trekking into the American West.

Few people today would seriously question the need for the use of insecticides. It would be just about as logical to advocate the abandonment of all

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agricultural pursuits and the return to the hunting and fishing age in order to avoid soil erosion as to recommend that we should refrain from using chemicals for pest control. Soil cultivation or chemical pest control practices may be beneficial or harmful depending upon the complete set of conditions present where they are used. Indiscriminate cultivation of the soil may cause untold damage, and the author submits that the indiscriminate use of chemicals for the control of plant pests may be of a similar order. The introduction of such quick acting and highly toxic chemicals as DDT has served to focus attention on this problem. It is encouraging to note that such outstanding entomologists as Dr. P. N. Annand[1], Chief, Bureau of Entomology and Plant Quarantine, Washington, D.C. and Dr. V. B. Wigglesworth[11], Director, Agricultural Research Council, Unit of Insect Physiology, Cambridge, England, have directed attention to this matter.

The most insidious feature of this problem is that the results are not always so soon apparent as in the case of DDT. This versatile insecticide, frequently spoken of as being selective, is in reality probably effective against more insects than any other chemical extensively tested up to this time. The fact that it does not kill all insects and related arthropods such as mites, is generally regarded as a decided weakness. This point will be dealt with in more detail later. The fact remains that at least some of the failures of DDT in pest control are almost immediately apparent. When DDT is applied to apple trees to control codling moth, on which it is extremely effective, it has the serious fault of killing many of the predators of pest mites and the latter begin to build up, being freed from attack by those other species which normally prey upon them. Consequently, it becomes a case where the fruit grower is trading one pest for another. The obvious solution according to the insecticide entomologist is to include something to destroy the mites. If this is accomplished successfully, and it may quite well be, will this be the end of the difficulties? That is the important question we all want answered. Nor is it just a question of codling moth and mites since this same phenomenon occurs frequently with respect to the control of other pests.

The author of this paper was a field entomologist in the fruit producing sections of the Province of Nova Scotia for a period of eleven years. It was his job to visit fruit growers, examine their orchards and advise them on their pest control problems. In considering the problems to be dealt with, the outstanding success attendant upon the early attempts at chemical control of insects and the vast improvement in the techniques of application made it appear only reasonable to expect that in the period of a few years, intensive control practices should reduce the orchard pest problem almost to the vanishing point. The author's disillusionment began when this result failed to occur and instead insect control problems actually intensified over the years. While it is true that we can now control almost any specific pest with which we have to deal, nevertheless, the problem of controlling pests is more acute than ever and the expense of the control program has increased many fold with the end not yet in sight.

The question that growers must eventually decide is whether the cost of control is economically justified. Research men should occasionally take time out from their hectic scramble of trying to concoct new chemicals or of ransacking the pharmacopoeia for old ones that will destroy all kinds of plant pests and ask themselves whether they are making any real progress or merely chasing a phantom. No one can definitely answer this question at present but enough evidence is available to enable us to speculate with some rationality on what the final outcome may be.

Some interesting evidence has been gathered during the past five years in connection with long-term studies on spray chemicals in Nova Scotia apple orchards. In the early part of World War II, when agricultural research programs were cut in favour of a greater war effort, some of the research men took time out to examine in retrospect the problem of apple orchard insect control. This review brought to light the fact that all of the important apple insects now causing orchardists concern had been present from the early days of apple growing but most of them had not been of importance until recently. This will be illustrated by brief reference to a few cases.

The oystershell scale, *Lepidosaphes ulmi* (L.), is recorded as being an occasional pest of young apple trees in Nova Scotia for over half a century but it did not become of importance until about fifteen years ago. In the second half of the decade beginning in 1930 it became a pest of major importance and killed many hundreds of trees and seriously damaged thousands of others. Whole orchards became heavily infested, the bark on the limbs and twigs becoming completely encrusted with scales in many instances. A survey showed that the insect was rarely a pest of any importance on unsprayed trees although it could be found on most of them in small numbers. In all cases the severe injury was found in sprayed orchards and usually those most thoroughly sprayed had the greatest populations of scales. Investigation showed that the reason for this phenomenon was the destructive action of sulphur sprays on the parasites and predators which under normal conditions keep the scale population at a low level. A recent paper by Lord[7] has described the normal biological control mechanism and how this is upset by the application of sulphur. Two natural enemies normally keep this scale under control in Nova Scotia; a parasitic chalcid wasp, *Aphelinus mytilaspidis* LeB., and a predacious mite, *Hemisarcoptes malus* (Shimer), usually being associated with the scale on unsprayed trees. Sulphur in any form has an inhibiting effect on both of these natural enemies but while the so-called 'mild' or elemental sulphurs are not detrimental to the scales, the more caustic lime-sulphur tends to destroy them. In Nova Scotia several applications of fungicide sprays are necessary for the control of apple scab. About 1930 the mild sulphur sprays came into prominent use and it was only a few years later that the scale population attained dangerous proportions. Growers began to ask what caused this tremendous build-up of scale but few would have seen any direct connection between the change in spray program a few years earlier and the occurrence of outbreaks of this pest. It has been found in experimental blocks of orchards that oystershell scale populations may be manipulated at will by varying the number of sulphur sprays applied. When copper or certain organic fungicides are substituted for sulphur the natural enemies of the scale increase and bring about its control.

A similar history respecting the European red mite, *Metatetranychus ulmi* (Koch) (*Paratetranychus pilosus* C. & F.), in apple orchards has been recorded. Table I shows the relative number of mites and their eggs at the population peaks in a five year test where the same fungicides were used throughout the entire period beginning in 1943.

TABLE I

Average peak of infestation of European red mites and eggs per leaf.

	1944	1945	1946	1947
Copper sprays only	16.0	0.1	2.0	46.0
Mild sulphur sprays only	170.0	67.0	166.0	309.0

It will be seen that while the numbers of mites have varied somewhat under both treatments the populations have not reached serious proportions on the copper treatments, while on the sulphur-sprayed area the numbers were so high

that by 1947 the cumulative effect of mite injury had seriously reduced the production of fruit. This build-up where sulphur was used is due to the fact that certain predators that feed on the mites are destroyed by sulphur. These results have been fully substantiated by the data from other studies.

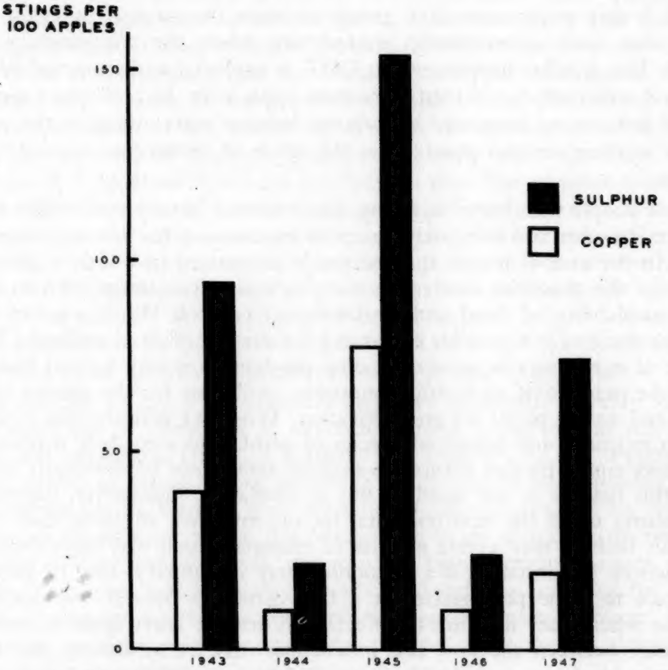
The history of the codling moth—the world's most important apple pest—in Nova Scotia closely parallels that of the oystershell scale. In short, the codling moth, while present, was of little importance for half a century in either sprayed or unsprayed orchards. About fifteen years ago it began to increase in numbers and within ten years became a major pest. It is worth noting that it did not increase appreciably on unsprayed trees but the build-up in population was in some of the best-cared-for orchards. It is likely that the continuity of crops has a bearing on the population trends but it is quite evident that this is not the most important factor in population increase.

Many explanations have been presented of the growing importance of codling moth as a pest. Dr. W. S. Hough[6] of the Virginia Experiment Station has shown that strains resistant to certain insecticides may be developed. The writer is of the opinion that this explanation is acceptable only if we are prepared to concede that a strain that is resistant to an insecticide has also a higher reproductive potential. Cutright and his co-workers[4] in Ohio have outlined a number of reasons for the severity of codling moth injury in that State. In addition to the development of resistance to lead arsenate they mention such factors as (a) favourable climatic conditions in certain geographical areas, (b) concentration of orchards in certain areas, (c) old orchards more favourable for this insect, (d) greater susceptibility of certain varieties and (e) unsanitary orchard practices. While these and other reasons may be valid at times, it appears doubtful that, either singly or combined, they can wholly account for the actual increase in populations of codling moth in sprayed as compared with unsprayed orchards.

The accompanying graph shows the results of studies on this insect in an experimental orchard. This orchard had been heavily infested with codling moth for several years before the experiment was commenced and records have since been kept on the degree of infestation within the orchard as well as in the surrounding ones. There appears to be little doubt but that the use of sulphur influenced the codling moth population, possibly through an effect on parasites or predators or both.

While the results of this study need further verification, the data suggest that more attention should be given to this line of approach to the insect control problem.

The Fruit Insects Unit of the Division of Entomology, Dominion Department of Agriculture[9], has instituted long-term studies on insect population trends in sprayed orchards. This program includes studies on the orchard fauna and their reaction to the more important spray chemicals, and a recognition of the interrelation of problems involving insect and disease control as well as of other horticultural practices which are a part of fruit production. It is recognized that there has been too great a tendency for scientific workers to compartmentalize the work within their immediate sphere of influence. This has tended to throw production and research programs out of balance and to focus attention on some particular aspect rather than to regard fruit growing as an integrated problem. The work of Haseman[5] in Missouri on the effect of soil minerals on the pest populations of plants supports this point of view. Prof. E. H. Strickland[10], has very clearly pointed out the inherent dangers in using such potent insecticides as DDT over wide areas. Other authors, including some of our more outstanding



Effect of Sulphur versus Copper Sprays on Codling Moth Infestation

entomologists have expressed, occasionally, the opinion that chemicals cannot be depended upon for the elimination of insect problems.

Is it to be considered an entomological triumph, when at considerable expense, a fruit grower is able to eliminate the codling moth as a pest of economic importance but has his crop severely injured by leaf rollers or mites? Is it a sign of progress when with great effort, and the extensive use of chemicals, pests are maintained at such a level that the grower has been able to produce saleable fruit only to find that the soil has become impregnated with poisonous materials to the extent that it is unproductive? In other words, to use a common cliché, is it not possible to win the battle and lose the war?

The writer is of the opinion that the ultimate value of spray chemicals can be determined only by long-term ecological studies of the problems involved. Dr. A. J. Nicholson[8], of Australia, has pointed out the dangers involved in relying on the immediate results of insecticide tests. He very properly questions whether a spray which gives an excellent immediate control of a pest can be depended upon to give equally good results when the spray is applied to the same area for a number of years. He answers the question in the negative, on the basis that despite a reduction in population there may be an increase in the survival potentialities of the species concerned. This, he points out, is probably due to the reduction in competition which may result from the impact of the spray on

those other species which are competitors of the species the spray was intended to control. There is, however, a further point that Nicholson has not touched on but which is of probably greater importance. This point is that although the spray may produce the effect desired on the original pest it was designed to control, it may at the same time greatly increase the survival potential of other species that were economically unimportant when the treatments were first applied. This is what happens when DDT is applied for the control of codling moth and when sulphur is used to control apple scab. In both cases species that were of little or no economic importance became pests owing to the enormous increase in their survival potential as the result of treatments applied for other purposes.

Most people who know anything about natural history realize that in nature there are elaborate and intricately balanced mechanisms for limiting animal populations. In the case of insects this balance is maintained in a variety of ways but mostly by the pressures exerted by the physical environment such as weather, by the availability of food and by biological control. While we can do little about the weather it is possible to control the amount of food available. Since the purpose of agriculture is to increase crop production it may be said that, on the whole, the practice of agriculture improves conditions for the species of insects which feed on the plants we are cultivating. When we consider the competition between injurious and beneficial species of plants and animals it is obvious that the relative equilibria that nature has evolved should not be drastically disturbed. While this balance is not absolute but is constantly fluctuating, depending on the pressures of all the environmental factors involved, anything that critically alters this balance may create a series of changes which may have far-reaching consequences. For instance, if a poisonous spray is applied it may be particularly destructive to some pest species at a time when its natural enemies are in a condition where they may not be affected. When the latter again become active the balance between the host and its enemies may be so altered that the host species may be almost entirely eliminated by the preponderance of enemy species which are present. The immediate result then is highly desirable. The host species, however, is so decimated that the natural enemies, if they depend entirely on the one host for their maintenance, as many parasite species do, also decrease in density. This scarcity of natural enemies allows the pest species to increase in numbers until it again occurs in outbreak form or is controlled by a resurgence of its parasites and predators. If the environment provides adequately for the physical requirements of the species, then the species would increase even to the point where it is too numerous for its food supply, unless natural enemies or man intervene. It will be seen, consequently, that for insects existing within their normal climatic range, and with an ample food supply, the interspecific competition afforded by other organisms is of the utmost importance and we cannot afford to ignore it. If we do so, and the competing forms are destroyed then we are 'on our own' as far as control of the pest species is concerned.

Man can only hope to mitigate the insect problem; he cannot eliminate it in an open environment. There is no doubt about the efficiency of modern insecticides in a closed environment such as dwellings, barns, greenhouses, etc., but beyond this there is a limit to what we may hope to accomplish. With annuals much can be done to protect the plants from attacks of specific insects but complications arise when we attempt to control all insects, even on annuals. The problem is still more difficult with perennials, especially fruit trees because of their extensive fauna and the greater possibility of accumulative effects from annual spraying. Those who feel that insecticides alone can be depended upon

to control all insect pests are not at all daunted when, for instance, the application of DDT to apple trees while practically eliminating the codling moth induces the build-up of tremendous populations of mites, woolly aphids or red-banded leaf rollers. They would solve the problem by adding another chemical and possibly another application or two of spray. New machinery and techniques for the application of chemicals are developed and, so we are carried from crisis to crisis, always hoping that the newest chemical or technique is the final requirement. And it must be remembered, and this is vital, that as this goes on the expense increases. It is true that if through the application of sprays we increase production and improve quality sufficiently then the extra cost is justified but it is apparent that there is a limit to this. The question which must be answered sooner or later is, can we adopt the policy of the complete control of insect pests by chemical means, ignoring biological factors, and produce crops economically? In some cases and with some crops the answer may be yes, and in others, no. It depends on many factors and the final criterion will be the cost involved. The practice of spraying may defeat its own purpose since it is a common experience with fruit growers that over a period of time, as thoroughness increases, the value of each application becomes proportionately less.

It is difficult to say what complications may eventually develop from the indiscriminate use of chemicals in establishing toxic conditions in soils and in affecting soil organisms. Dr. A. J. Carlson[2] has pointed out the possibilities of the development of extensive lead poisoning by the use of lead in motor fuel to prevent engine knock. Carlson is an outstanding physiologist and his reputation is not that of an alarmist. While this has nothing to do directly with the use of insecticides it does indicate how, unwittingly, highly potent poisons may be distributed. A recent article by J. Sidney Cates[3] indicates some of the dangers involved in using some of the new insecticides in respect to soil toxicity. It could happen that posterity will condemn the present generation as despoilers on account of the indiscriminate dissemination of poisons.

The methods used in many cases in testing the effects of various agricultural chemicals on soils, leaves much to be desired. As pointed out previously these effects may exhibit themselves very slowly and several years may elapse before the final results become known. Furthermore, the mere application of excess quantities of a chemical to a small plot of soil or to a pot of it in a greenhouse and the making of a few casual observations later does not constitute a satisfactory basis for making recommendations to farmers. In other words, the present methods used by investigators in testing agricultural chemicals are entirely too empirical and should be regarded with acute skepticism. This applies not only to the work of the scientific staffs of industrial organizations but to that of governmental officers as well.

There are a number of reasons, most of them economic, why this policy has been allowed to develop as it has. There are many incentives established and various pressures exerted to induce the carrying on of insecticide testing but there is little to encourage long-term ecological studies of the changes in the complex biological relationships that may be brought about by the application of spray chemicals. The results of such work are so slow in coming to light that the problem is side-tracked because no organization is behind it and only the primary producer stands to profit immediately from any progress in this field. The farmer should be interested in this line of approach but for the most part he too is subjected to economic pressures to get immediate results and the problems are mostly too abstruse for him to comprehend fully.

As an example of the trend in research work, of sixty-one papers presented at a recent entomological conference fifty-six dealt with the empirical testing of insecticides and none was concerned with the cumulative effects of the application of these chemicals over a period of time. While this may be an exceptional case it is an indication of the trend that has been apparent for a considerable period and an example of the pressures to which scientific workers are likely to succumb.

Scientists are probably influenced in their approach to problems in much the same way as their brothers in other fields of human endeavor. Our thought patterns are influenced by contemporaneous thinking and it is no easy matter to put our fingers on the weak points in our approach to problems.

In spite of the fact that the following statement is likely to be criticized the writer is of the opinion that the tendency to prescribe mathematical formulae to explain complex biological phenomena is very often premature and tends to suppress rather than stimulate the elucidation of ecological phenomena.

It is true that the objective of the economic entomologist is a measurable, which is to say, a quantitative result. He is trying, by the reduction of insect damage, to produce an increase in the cash return for the crop. Statistical methods are designed to evaluate this result and to eliminate errors due to sampling and they are certainly of great value.

On the other hand, the use of statistics is restricted to relatively simple situations and there is always a danger that the complex field situation may be artificially simplified in order to make the statistical treatment manageable. Furthermore, the statistical treatment usually deals only with the end results of treatment, comparing treated and check areas. The manner in which the result has come about is too often neglected. It is forgotten that similar end results may develop through different sequences of events.

For these reasons the writer feels that a comprehensive study of the development and interactions of the populations of pests and their natural enemies in treated and untreated orchards, by experienced observers may provide, without extensive statistical manipulations, data substantially more accurate and interesting than are secured by the mere comparison of end results, even if the figures obtained are statistically significant.

Dr. Wigglesworth[11] has pointed out "It may well be that in the long run an insecticide which kills 50 per cent of the pest insect and none of its predators or parasites may be far more valuable than one which kills 95 per cent but at the same time eliminates its natural enemies." Can we establish experimental procedures designed to give statistical significance when problems of this nature are dealt with? At present, at least, the answer must be in the negative.

It should be recognized that each individual orchard with its environment is a dynamic biological community within which the various components fluctuate according to the various pressures involved and no two orchards are directly comparable. There may be a tendency toward similarity if conditions and treatments have been approximately the same over a period of time and a state of equilibrium has been approached. It is unlikely that the static state or a state of complete equilibrium will ever become established. It is not possible to make direct comparisons when so many variables are involved and it is for this reason that statistical methods may fail to have significance and attempts to use them lead to misinterpretation and frustration. It would appear that there is still plenty of scope for the sometimes despised observational methods of the old-time naturalists.

If in attempting to control our insect pests we are simply trading off one group of pests now for another group in the future then the only damage will be the relative costs of the control measures and the degree to which control of those new pests can be attained. There may be, however, inherent in our present policies, the danger of creating agricultural and nutritional problems with such far-reaching results that we cannot simply return to some previous stage and start over again. The writer is not prepared to say that the trend toward the use of chemicals destructive to more and more species must necessarily lead to such a bleak future nor is it his desire to make this a disputation on natural versus chemical control. The important point is to re-examine our whole approach so that the relative values and shortcomings of each may be determined in the light of their total and long-term effects.

A truly scientific approach to agricultural problems is imperative. The policies at present predominating are short-sighted and empirical and our whole philosophy needs a thorough re-examination. As a basis for argument the following approach to the problems of pest control is suggested:

Agricultural practices are the conscious attempts of man, who is himself a factor in the biotic community, to so alter the interactions of the factors in his environment that he may bring about advantages favorable to himself in his competition with other species. There must be recognition of the fact that he is a part of the whole and when he wishes to alter the normal functioning of the component parts he must realize that although he can single these parts out for study he cannot, in the natural community, alter one factor without disturbing many others. It follows then that in the control of insects the measures employed must be considered not only in relation to a few pest species but in their effects on the ecologic whole which would include the total effect of his efforts on the fauna and flora of the whole community.

If we cannot isolate the insect pest problem from the problems of agriculture it is equally true that we cannot deal with the insect pests alone when we apply chemicals which are indiscriminately destructive. It seems an obvious conclusion that we cannot hope to find chemicals that will kill only the injurious species and be innocuous to the beneficial forms. The hope that we can destroy all insects, including the pests, without in some way damaging irreparably the biotic and physiological relationships of nature seems equally barren.

If the foregoing contentions are even approximately correct then it may follow that the widespread and more or less general use of chemicals which may be highly toxic to a wide variety of species of living things is dangerous and may set up 'chain reactions' that may have far-reaching results. It is suggested, therefore, that instead of using chemicals which kill many species, we attempt to discover chemicals which are highly specific for particular pests. If a chemical were developed that was highly specific for apple scab and did not affect other plant or animal species it would solve several serious pest control problems in apple orcharding. Even if this chemical was effective against fungi but innocuous to animal life much would be accomplished. For the present at least we may assume that no chemical is likely to be found that will give complete protection from all pests, leave no poisonous or otherwise objectionable residues on the plant or in the soil and be innocuous to the metabolic processes of the plants on which it is used. All chemicals used must be carefully studied to determine what over-all effects they have. In the meantime we should study carefully and utilize as fully as possible all the natural factors involved in the environmental resistance to pests.

Finally, the writer believes we should accept as a fundamental concept the

proposition that crops should be grown primarily for the purpose of satisfying man's food requirements and not as a means of making particular human activities commercially profitable regardless of the overall effect on human welfare.

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